CLAIMS

1. An improved vortex mill for milling a substantially particulate solid material, said mill including at least one working chamber having

   a) a side-wall defining a generally cylindrical, inward facing surface;

   b) a first end wall and a second end wall arranged transversely to said side-wall and having respective end surfaces formed contiguously with and transversely to said inward-facing surface, thereby to define therewith said at least one working chamber;

   c) at least one working fluid inlet for introducing a generally tangential flow of working fluid into said at least one working chamber thereby to create a vortex flow therein;

   d) at least one discharge port formed in at least one of said end walls, said at least one working fluid inlet and said at least one discharge port cooperating so as to facilitate a vortex flow of the working fluid introduced via said at least one working fluid inlet, said at least one discharge port permitting discharge of working fluid and milled material from said at least one working chamber;

   e) at least one feed inlet for introducing a substantially particulate solid material into said at least one working chamber so as to be taken up in a vortex flow of the working fluid, thereby to provide milling of the solid material, milled inlet material being discharged via said at least one discharge port; and

   f) apparatus for inducing controlled perturbations in the flow of the working fluid in said at least one working chamber, thereby to improve the milling of the solid material in the vortex flow.

2. An improved vortex mill according to claim 1, also includes at least one outer casing configured to surround and enclose at least one said working chamber so as to be spaced therefrom and thereby to define therewith an outer fluid flow volume, and wherein said at least one outer casing includes:

a) at least one outer working fluid inlet for introducing a flow of working fluid into said outer fluid flow volume, thereby to induce a fluid flow therein, operative to discharge through said working fluid inlet into said at least one working chamber;

b) at least one outer feed inlet for introducing substantially particulate solid material into said at least one working chamber via said at least one feed inlet; and

c) at least one outer discharge port for permitting discharge of milled particulate solid material from said at least one working chamber via said discharge port.

3. An improved vortex mill according to claim 1, wherein said side-wall of said at least one working chamber is formed of at least one functional insert having a closed shape generally coaxially disposed within said working chamber, each said at least one functional insert having a generally cylindrical side wall formed therein.

4. An improved vortex mill according to claim 3, wherein said at least one functional insert includes at least a first and a second functional insert having substantially similar configurations and a substantially similar angular orientation with respect to each other.

5. An improved vortex mill according to claim 3, wherein said at least one functional insert includes at least a first and a second functional insert having substantially dissimilar configurations with respect to each other, said dissimilar functional inserts being disposed in a predetermined configuration sequence within said working chamber.

6. An improved vortex mill according to claim 5, wherein said dissimilar functional insert s, are dissimilar with respect to at least one of the parameters selected from the group which consists of: diameter, height, shape of said inward facing surface, and mechanical insert elements.

7. An improved vortex mill according to claim 1, wherein said at least one working chamber includes at least one flow restriction element having at least one orifice formed therein, said at least one orifice having a predetermined size, orientation and disposition, said at least one flow restriction element mounted in a fixed, coaxial disposition relative to said at least one functional insert, thereby to increase dwell time of the particulate solid material to be milled therewithin.

8 An improved vortex mill according to claim 7, wherein said at least one flow restriction element has a configuration selected from the group which consists of: flat, planar, conical, frustum, convex, polyhedral, dished, and a surface generated by rotation of a line about the axis of said chamber in accordance with a predetermined geometric function.

9 An improved vortex mill according to claim 7, wherein said at least one orifice is formed coaxial with said flow restriction element.

10 An improved vortex mill according to claim 7, wherein said at least one flow restriction element is formed integrally with said at least one working chamber.

11 An improved vortex mill according to claim 7, wherein said flow restriction element is non-fixably supported within said at least one working chamber.

12. An improved vortex mill according to claim 7, wherein said flow restriction element is fixably mounted between a first functional insert and a second functional insert, thereby to control comminution of solid material.

13. An improved vortex mill according to claim 7, wherein said flow restriction element has vanes disposed thereon, thereby to deflect solid particles within the vortex flow generally away from said inward facing surface of said side wall and generally towards the vortex axis.

14 An improved vortex mill according to claim 7, wherein said flow restriction element has vanes disposed thereon, thereby to deflect solid particles within the vortex flow generally away from the vortex axis and towards said inward facing surface of said side wall.

15. An improved vortex mill according to claim 7, wherein said flow restriction elements have formed thereon at least one rib-shaped baffle, each of said rib-shaped baffles being concentric with said cylindrical side wall thereby to reduce the velocity of solid particles adjacent to said flow restriction element and thus to prevent premature discharge of the solid particles.

16. An improved vortex mill according to claim 1, wherein said apparatus for inducing predetermined perturbations includes at least one of the group which consists of:

a) a side-wall configuration which includes at least one of the group which consists of:

i) a plurality of substantially planar side-walls;

ii) at least one working fluid inlet formed within a formed recess located between adjacent said plurality of substantially planar side-walls, said inlet being disposed substantially parallel to said substantially planar side-walls and generally tangentially with respect to said working chamber, and

iii) at least one auxiliary working fluid inlet formed within at least one of said plurality of substantially planar side-walls, disposed substantially non-parallel to said substantially planar side-walls with respect to said working chamber, said at least one auxiliary working fluid inlet thereby to introduce additional working fluid flow into said working chamber, thereby to cause controlled perturbations in the vortex flow and also thereby to redirect flow of particles away from said planar side-wall across the vortex flow;

b) a side-wall configuration including at least one substantially planar side-wall formed within said generally cylindrical inward facing surface;

c) at least one auxiliary working fluid inlet formed in said side-wall, said at least one auxiliary working fluid inlet directed substantially non-tangentially to said side-wall and at a predetermined angle to the direction of vortex flow at a point of entry of working fluid thereby to enable introduction of additional working fluid flow generally non tangentially into said working chamber, thereby to create controlled perturbations in the vortex flow and also thereby for redirecting the flow of particles away from said side-wall across the vortex flow;

d) at least one mechanical insert element disposed on said inward facing surface, parallel to the axis of said working chamber, said mechanical insert element having a curved surface so as to be generally disposed away from said inward facing surface and towards said working chamber axis, thereby to redirect the flow of working fluid and particles of solid material away from said inward facing surface, and thereby to induce predetermined perturbations in the flow of working fluid; and

e) at least one auxiliary working fluid inlet disposed in said inward facing surface, said at least one auxiliary working fluid inlet associated with said at least one mechanical insert element, thereby to redirect flow of working fluid and particles of solid material away from said inward facing surface and thereby to induce predetermined perturbations in the flow of working fluid;

17. An improved vortex mill according to claim 1, wherein said apparatus for inducing predetermined perturbations in the flow of the working fluid includes apparatus selected from the group which consists of:

a) apparatus for controlling the entry flow rate of working fluid;

b) apparatus for controlling the rate of introduction of substantially particulate solid material into said working chamber;

c) apparatus for varying the working fluid pressure in said working chamber; and

d) apparatus for controlling the rate of discharge of particulate solid material.

18. An improved vortex mill according to claim 1, wherein said apparatus for inducing controlled perturbations in the flow of the working fluid is operative to limit the frequency to within the range 5Hz to 5.10^4kHz.

19. An improved vortex mill according to claim 1, wherein each of said end walls has a shape selected from the group which consists of: flat, planar, conical, frustum, convex, polyhedral, dished and a surface generated by rotation of a line about the axis of said chamber in accordance with a predetermined geometric function.

20. An improved vortex mill according to claim 1, wherein a relationship between diameter and height of said inward facing surface of said generally cylindrical side-wall is defined in accordance with a predetermined geometrical expression.

21. An improved vortex mill according to claim 20, wherein said geometric expression is $H<2.5D$, in which D is the diameter of said generally cylindrical side-wall inward facing surface and H is the height thereof.

22. An improved vortex mill according to claim 1, wherein said at least one feed inlet has an orientation selected from the group which consists of:

a) disposed in said end wall co-axial with said working chamber;

b) disposed in said end wall co-axial with said discharge port formed in said working chamber;

c) disposed in said at least one of said end walls, eccentrically to the axis thereof;

d) disposed co-axially with said discharge port formed in said first end wall, and including a distal end of said at least one feed inlet fixably attached to said inner surface of said second end wall; and

e) disposed in said side-wall.

23. An improved vortex mill according to claim 1, wherein said at least one feed inlet includes a baffle apparatus generally disposed at a distal end of said feed inlet, said baffle to reduce the kinetic energy of feed particles entering said working chamber through said feed inlet, thereby to reduce feed particle velocity and thereby to diffuse particle flow into said working chamber.

24. An improved vortex mill according to claim 1, wherein said at least one feed inlet communicates with said working chamber via an opening, said opening having a configuration and position which is selected from the group which consists of:

a) a transverse opening in a distal end of said feed inlet;

b) a generally slot-shaped opening in said feed inlet orientated parallel to the axis of said working chamber; and

c) a generally slot-shaped opening in said cylindrical feed inlet orientated at a predetermined angle to the axis of said chamber.

25. An improved vortex mill according to claim 1, wherein said at least one feed inlet includes apparatus for introducing a flow of substantially particulate solid material into said chamber at a selected rate.

26. An improved vortex mill according to claim 25, wherein said apparatus for introducing a flow of substantially particulate solid material into said working chamber includes an ejector, said ejector drawing feed solid material from a feed vessel and, thereafter introducing a flow of substantially particulate solid material into said working chamber.

27. An improved vortex mill according to claim 1, wherein said at least one discharge port formed in at least one of said end faces is formed substantially coaxial with respect to said working chamber, said discharge port having a configuration selected from the group which consists of:

a) circular; and

b) annular

28. An improved vortex mill according to claim 1, wherein the configuration of said at least one discharge port formed in at least one of said end faces is defined accordance with an expression $S_{outlet} > 10^{-3}D^2$,

in which S_{outlet} is the cross-sectional area of said discharge port; and

D is the diameter of said inward facing surface.

29. An improved vortex mill according to claim 1, wherein said at least one feed inlet and said at least one discharge port are substantially mutually co-axial.

30. An improved vortex mill according to claim 1, wherein said at least one discharge port includes apparatus for separating discharged milled particulate solid material from working fluid and apparatus for collecting discharged milled particulate solid material.

31. An improved vortex mill according to claim 1, also includes at least one auxiliary discharge port formed in at least one of said cylindrical side-wall and said end walls.

32. An improved vortex mill according to claim 31, wherein said at least one auxiliary discharge port includes means for discharging partially milled particulate solid material from said at least one auxiliary discharge port and further includes means for receiving discharged partially milled particulate material from said at least one auxiliary discharge port, and for re-

introducing the discharged partially milled particulate solid material into said at least one working chamber via a conduit and an auxiliary feed inlet.

33. An improved vortex mill according to claim 32, wherein said auxiliary feed inlet is coaxially formed with said feed inlet.

34. An improved vortex mill according to claim 1, wherein said working chamber has at least one recess formed in at least one of said inward facing surface of said generally cylindrical side-wall and said end surfaces of said end walls, thereby to induce a controlled perturbation in the vortex flow.

35. An improved vortex mill according to claim 34, wherein said at least one recess includes at least one working fluid inlet formed in fluid flow communication with said recess.

36. An improved vortex mill according to claim 34, wherein said at least one recess includes at least one feed inlet for particulate solid material formed in fluid flow communication with said recess.

37. An improved vortex mill according to claim 34, wherein said at least one recess includes at least one discharge port for comminuted particulate solid material formed in fluid flow communication with said recess.

38. An improved vortex mill according to claim 34, wherein said at least one recess has at least one portion filled with a fluid permeable diffusing medium, thereby to enable dispersed ingress of working fluid into said working chamber.

39. An improved vortex mill according to claim 1, wherein said apparatus for inducing controlled perturbations in the flow of the working fluid in said at least one working chamber, includes at least one mechanical elastic oscillation generator mounted in association with at least one of said inward facing surface and end walls of at least one working chamber, thereby to

cause controlled perturbations in the flow of the working fluid in said at least one working chamber.

40. An improved vortex mill according to claim 1, wherein said apparatus for inducing controlled perturbations in the flow of the working fluid in said at least one working chamber, includes at least one generally wear resistant mechanical element freely disposed within said working chamber, said mechanical element being caused to move within said working chamber by the vortex flow.

41. An improved vortex mill according to claim 1, wherein said at least one working chamber includes a plurality of working chambers arranged to facilitate flow of particulate material there-among, in a predetermined sequence.

42. An improved vortex mill according to claim 41, wherein each of said plurality of working chambers includes at least one discharge port for discharging particulate solid material therefrom and each said at least one discharge port has associated therewith apparatus for receiving discharged material therefrom, and for introducing the discharged material into said feed inlet of a predetermined succeeding working chamber of said plurality of working chambers.

43. An improved vortex mill according to claim 41, wherein at least one of said plurality of working chambers includes at least one auxiliary discharge port formed in at least one of said cylindrical side wall and said end walls, for discharging therefrom a preselected generally over-sized and partially milled proportion of the discharged particulate solid material and each said auxiliary discharge port has associated therewith apparatus for receiving the preselected proportion of the discharged material therefrom, and for introducing the preselected proportion of discharged material into said feed inlet of a predetermined succeeding working chamber of said plurality of working chambers.

44. An improved vortex mill according to claim 1, wherein said end walls have end surfaces having formed thereon at least one rib-shaped baffle, each of said rib-shaped baffles being concentric with said cylindrical side wall thereby to reduce the velocity of solid particles adjacent to said end surface and thus to prevent premature discharge of the solid particles.

45. An improved vortex mill according to claim 44, wherein said at least one cylindrical rib-shaped baffle includes a plurality of concentric cylindrical rib-shaped baffles thereby defining a plurality of concentric annular channels thereby to reduce the velocity of solid particles adjacent to said end surface and to prevent premature discharge of the solid particles.

46. An improved vortex mill according to claim 45, wherein said plurality of concentric annular channels includes a plurality of auxiliary fluid inlets for introducing a flow of working fluid within each of said annular channels generally in the direction of rotation of the vortex flow, thereby accelerating the flow of solid material adjacent to said inner surface of said end wall.

47. An improved vortex mill according to claim 44, wherein said rib-shaped baffles are formed as a configuration selected from the group: cylindrical, conical frustum and inverted conical frustum.

48. An improved vortex mill according to claim 44, wherein said rib-shaped baffles have predetermined openings formed therein.

49. An improved vortex mill according to claim 44, wherein said rib-shaped baffles have predetermined openings formed therein, and said rib-shaped baffles have vanes disposed adjacent to said openings and external to the circumference of said rib-shaped baffles, thereby to deflect solid particles within the vortex flow away from said inward facing surface of said side wall generally towards the vortex axis.

50. An improved vortex mill according to claim 44, wherein said rib-shaped baffles have predetermined openings formed therein, and have formed thereon vanes disposed adjacent to said openings and internal to the circumference of said ribs, thereby to deflect solid particles within the vortex flow generally away from the vortex axis and towards said inward facing surface of said side wall.

51. An improved vortex mill for milling a substantially particulate solid material, said mill including at least one working chamber having

a) a side-wall defining a generally cylindrical, inward facing surface;

b) a first end wall and a second end wall arranged transversely to said side-wall and having respective end surfaces formed contiguously with and transversely to said inward-facing surface, thereby to define therewith said at least one working chamber;

c) at least one working fluid inlet for introducing a generally tangential flow of working fluid into said at least one working chamber thereby to create a vortex flow therein;

d) at least one discharge port formed in at least one of said end walls, said at least one working fluid inlet and said at least one discharge port cooperating so as to facilitate a vortex flow of the working fluid introduced via said at least one working fluid inlet, said at least one discharge port permitting discharge of working fluid and milled material from said at least one working chamber;

e) at least one feed inlet for introducing a substantially particulate solid material into said at least one working chamber so as to be taken up in a vortex flow of the working fluid, thereby to provide milling of the solid material, milled inlet material being discharged via said at least one discharge port; and

f) at least one mechanical insert element disposed in said inward facing surface of said side-wall thereby to induce controlled perturbations in the flow of the working fluid in said at least one working chamber.

52. An improved vortex mill according to claim 51, wherein said working chamber includes apparatus for inducing controlled perturbations in the flow of the working fluid in said at least one working chamber, thereby to improve the milling of the solid material in the vortex flow.

53. A process for milling a substantially particulate solid material using an improved vortex mill, said process including:

a) introducing a generally tangential flow of working fluid into a generally cylindrical working chamber thereby to create a vortex flow therein;

b) feeding substantially particulate solid material sought to be milled into the working chamber such that the material is taken up in suspension in the vortex flow, thereby to apply comminution stresses to the suspended solid particles;

c) inducing controlled perturbations in the vortex flow, thereby to regulate the comminution stresses applied to the suspended solid particles and thus also the rate of milling thereof; and

d) discharging milled particulate solid material together with working fluid from the working chamber.

54. A process according to claim 53, wherein said step of inducing controlled perturbations includes the step of controlling the extent and frequency of the controlled perturbations of the flow of the working fluid, thereby to control the rate of milling of the substantially particulate solid material within the working chamber.

55.A process according to claim 53, and including the additional step of introducing into the working chamber a flow of working fluid via an inlet disposed at a predetermined angle to the direction of flow of the vortex.

56. A process according to claim 53, wherein said step of controlling the extent and frequency of the controlled perturbations in the flow of working fluid

includes at least one of the sub-steps selected from the group which consists of

a) adjusting the flow rate of working fluid entering generally tangentially into the chamber;

b) altering the feed rate of the particulate solid material;

c) adjusting the flow rate of the working fluid entering non-tangentially into the working chamber, at a predetermined angle to the direction of flow of the vortex; and

d) varying the working fluid pressure in the working chamber.

57. A process according to claim 53, wherein said step of feeding substantially particulate solid material includes the step of pneumatically transporting the substantially particulate solid material into the working chamber.

58. A process according to claim 57, wherein the vortex flow is formed about an axis extending transversely through the working chamber, and gives rise to an area of low pressure in the region of the axis, and said step of pneumatically transporting the substantially particulate solid material into the working chamber includes the step of exposing a feed of the material to the low pressure area in the axial region, thereby to cause the material to be drawn into the chamber.

59. A process according to claim 57, wherein said step of pneumatically transporting the substantially particulate solid material into the working chamber includes a step of drawing the substantially particulate solid material into the working chamber via an auxiliary feed inlet, such that said step of drawing the substantially particulate solid material into the working chamber is facilitated by a suction effect arising from the vortex flow tangential to the auxiliary feed inlet.

60. A process according to claim 57, wherein said step of pneumatically transporting the substantially particulate solid material into the working

chamber includes the step of operating an ejector with a flow of working fluid thereby drawing the substantially particulate solid material from a feed vessel, and introducing the substantially particulate solid material and working fluid into the working chamber.

61. A process according to claim 53, wherein said step of discharging particulate solid material includes the step of selectively discharging unmilled and oversized particulate solid material thereby controlling the extent of comminution in the working chamber.

62. A process according to claim 61, and also including a step of introducing the discharged unmilled and oversized particulate solid material into a working chamber for further milling.

63. A process according to claim 53, wherein said step of discharging particulate solid material includes the step of discharging particulate solid material from one of a plurality of working chambers, and said process also includes the additional step of feeding the discharged particulate solid material into a preselected working chamber of the plurality of working chambers for milling therein.